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Title: A Brief Introduction to Gamma and Neutron Radiation

Author(s): Karpius, Peter Joseph

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A Brief Introduction to Gamma and Neutron Radiation

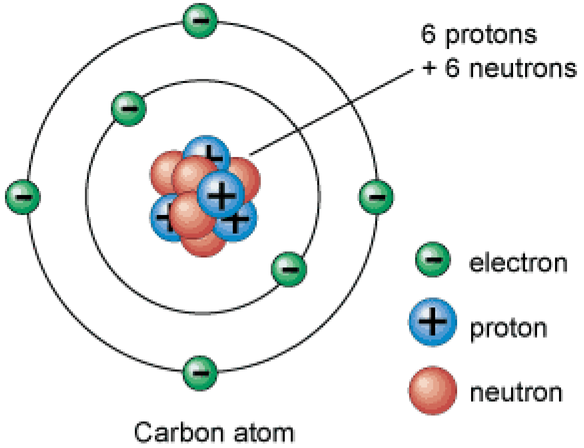
Pete Karpius

LA-UR-20-XXXXX

Objectives

- Describe gamma rays in plain English
- Give 3 reasons we measure gamma rays
- Describe shielding effect vs gamma energy
- List 4 components of the natural background
- Detail the main reason we care about neutrons
- List three good neutron moderators

Elements, Nuclides, and Isotopes



^{12}C (Carbon-12):

a) has 6 protons and 6 neutrons
b) Atomic number (Z): # of protons
c) Atomic Mass (A): # of protons + neutrons

Constituents of the Atom: Protons, Neutrons, and Electrons

Elements: Defined by the number of protons in the nucleus

Isotopes: atoms from same element but with different number of neutrons

Nuclides (or Radionuclides): a more general term specifying element and atomic mass

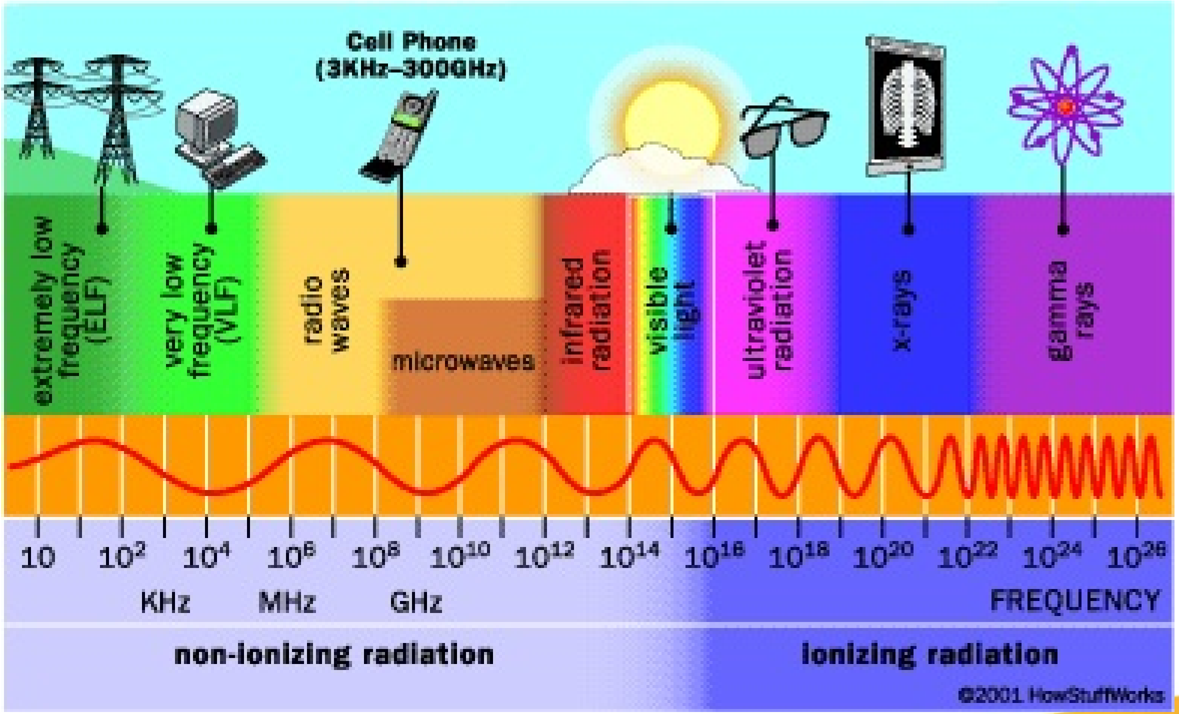
Why Measure Gamma Rays?

- Electromagnetic interactions are well understood.
- Gamma rays can be highly penetrating.
- We can extract information <u>passively</u>.
- We can extract information particular to a **radionuclide.**
  - What nuclides are present?
  - How much is there? (limited by self shielding)

^{235}U or ^{238}U vs. just "U"

What are Gamma Rays?

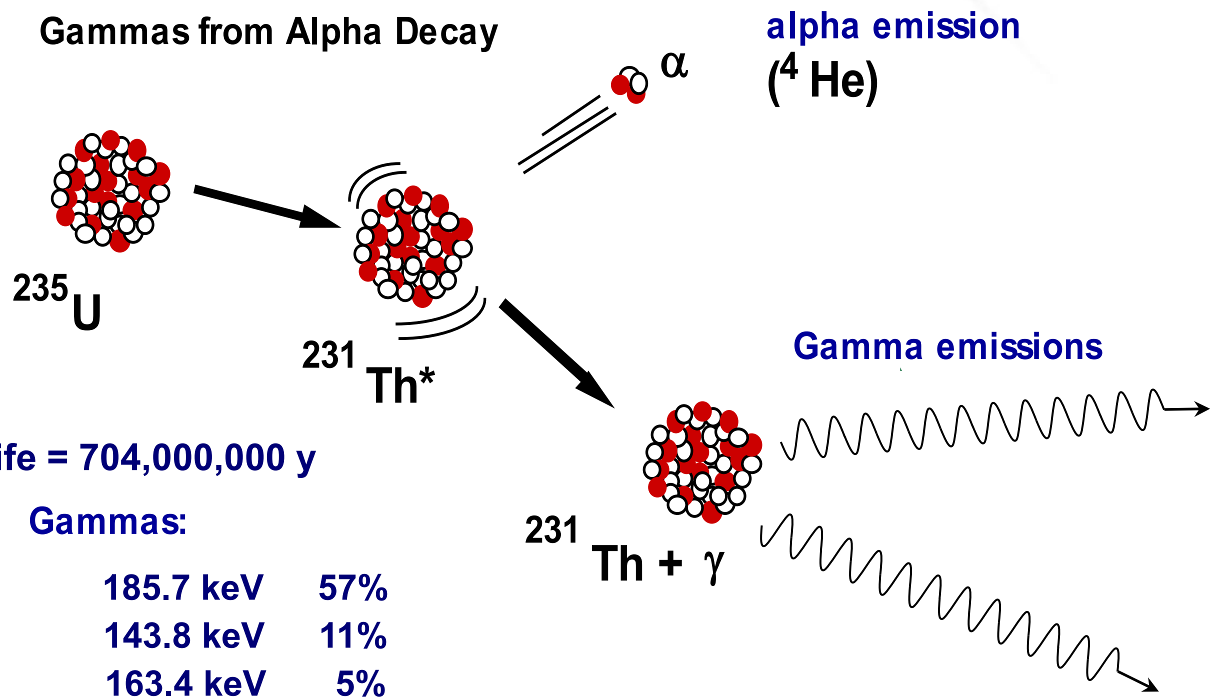
- Gamma rays are electromagnetic (EM) radiation that come from the atomic nucleus
  - EM radiation = light (visible and otherwise)



Origin of Gamma rays

GAMMA-RAY SIGNATURE

Gammas from Alpha Decay



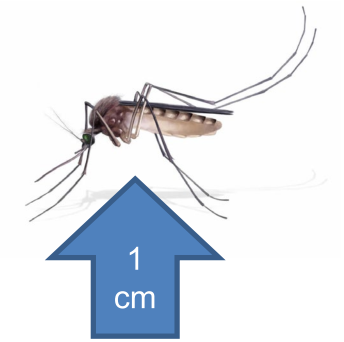
Half Life = 704,000,000 y

Gammas:

185.7 keV	57%
143.8 keV	11%
163.4 keV	5%
205.3 keV	5%

Gamma Ray Energies

- Units usually in kilo-electron volts (keV)
- 1 keV = 1,000 eV
- 1 MeV = 1,000,000 eV
- 1 TeV = 1,000,000,000,000 eV
  - About what it takes to lift a mosquito 1 cm



- Roughly speaking:
  - Low energy: ~ < 200 keV
  - Medium Energy: ~ 200 – 1000 keV
  - High Energy: > ~ 1000 keV

Gamma-Ray Interactions

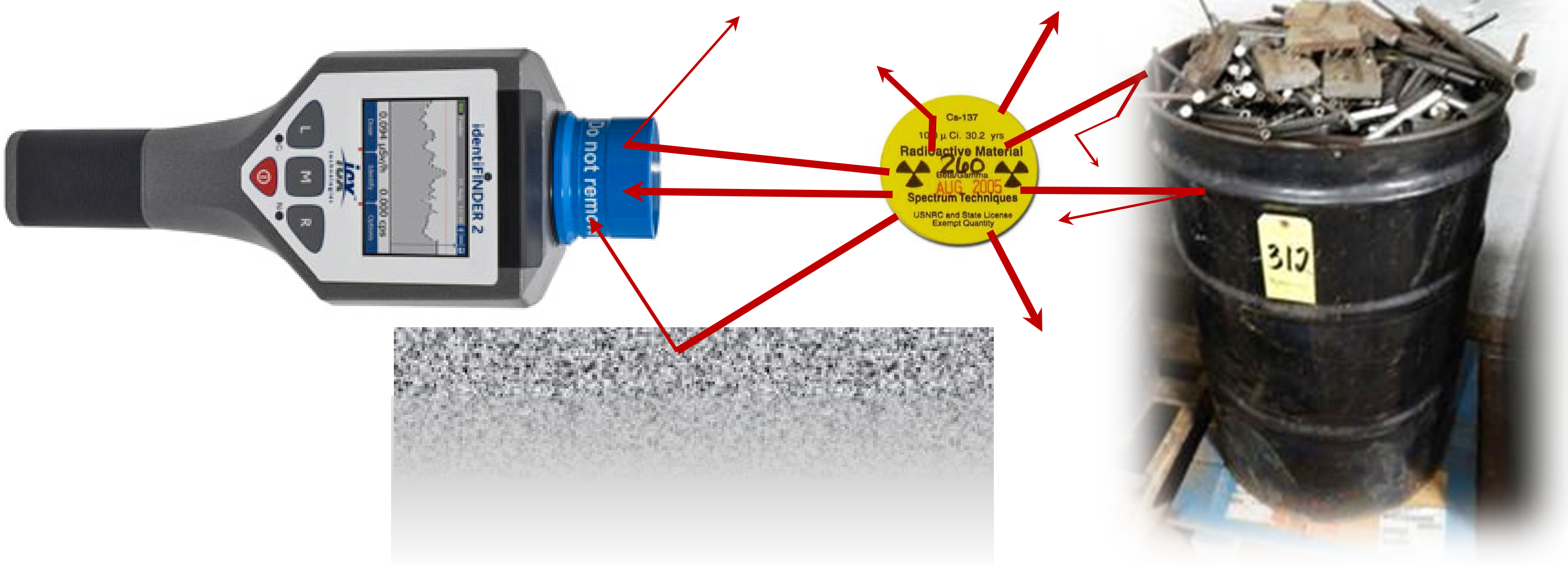
- Gamma rays interact with matter in many ways.
- One of those ways is scattering.
- Scattering of gamma rays is analogous to the ricochet of a bullet.
- Scattering can make the data for the same source look very different in different measurement configurations.

Gamma-Ray Scattering

Gamma rays scatter everywhere:

- In the detector
- In the surroundings
- In the source itself

Every time gamma rays scatter they lose energy.

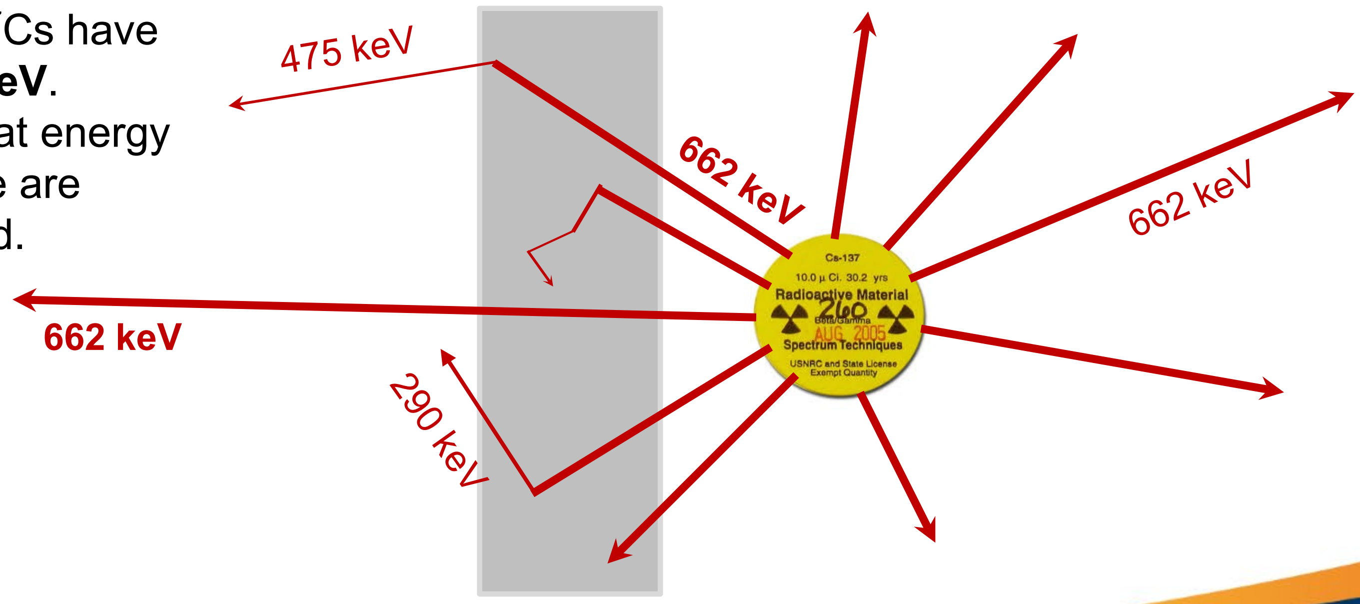


Scattering can complicate the data that you take in the field.

Gamma-Ray Attenuation (Shielding)

- Shielding reduces the intensity of full-energy gamma rays from a source
  - The lower the initial gamma energy the more effective the shield

The gammas from ^{137}Cs have a full energy of **662 keV**. They lose some of that energy as they scatter. Some are absorbed in the shield.

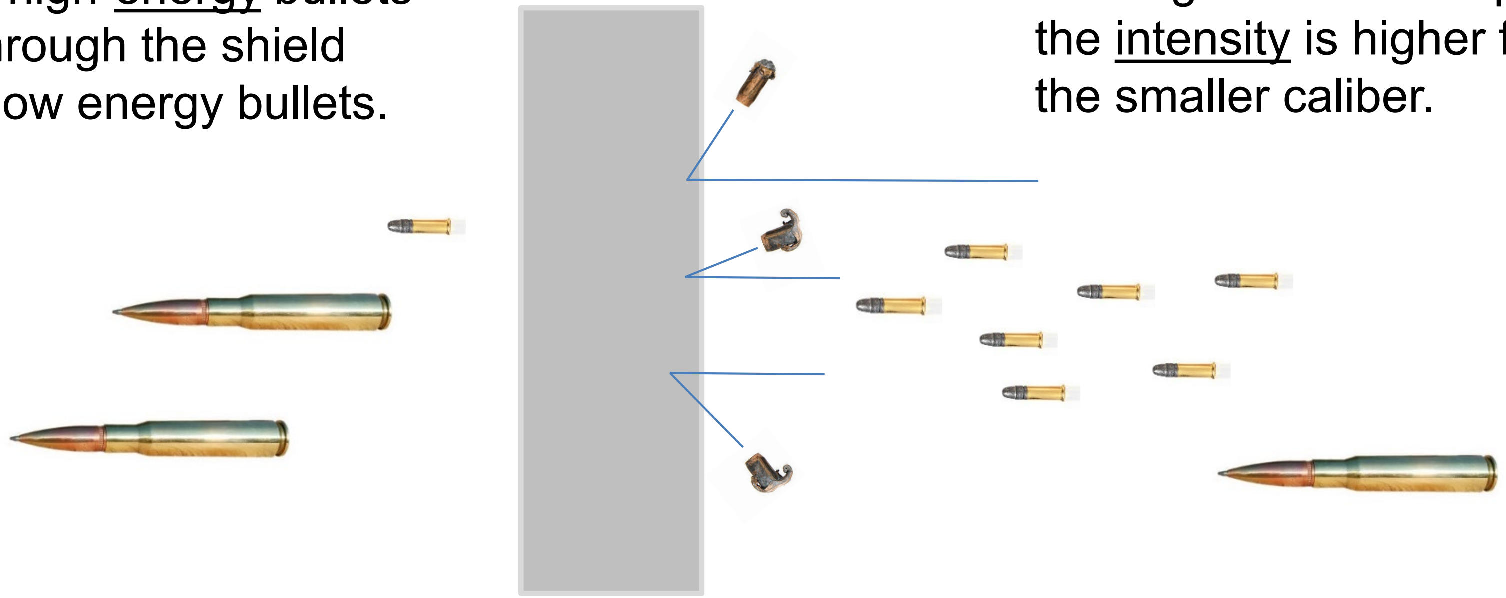


Shielding, Energy, & Intensity

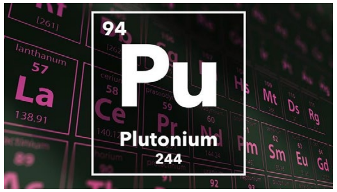
- Gamma rays are (sort of) like bullets.

More high-energy bullets get through the shield than low energy bullets.

Although in this example the intensity is higher for the smaller caliber.



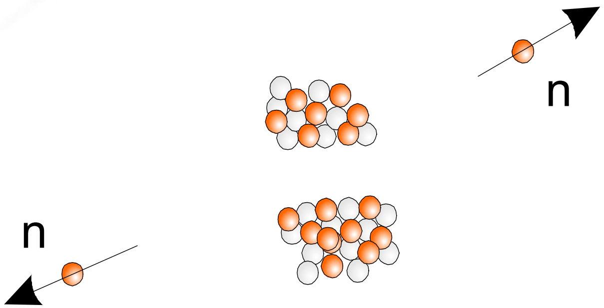
Why Measure Neutrons?



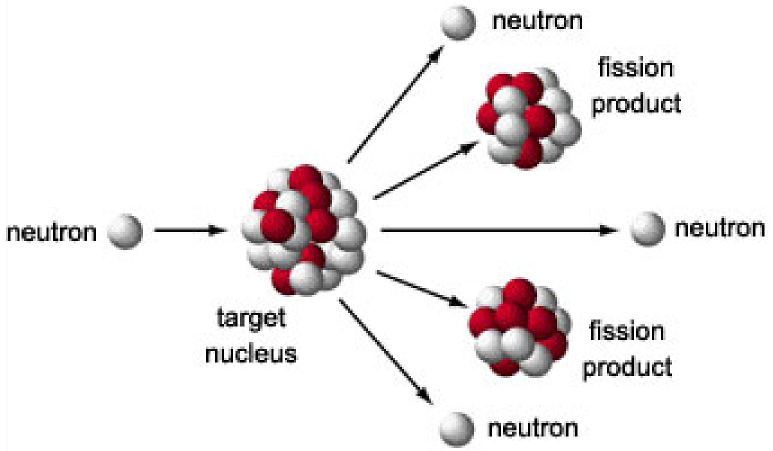
- Neutrons are a key signature of **plutonium**
- Neutrons can be highly penetrating.
- We can extract information passively.
- There are very few natural neutron sources compared to gamma sources

Common Origins of Terrestrial Neutron Radiation

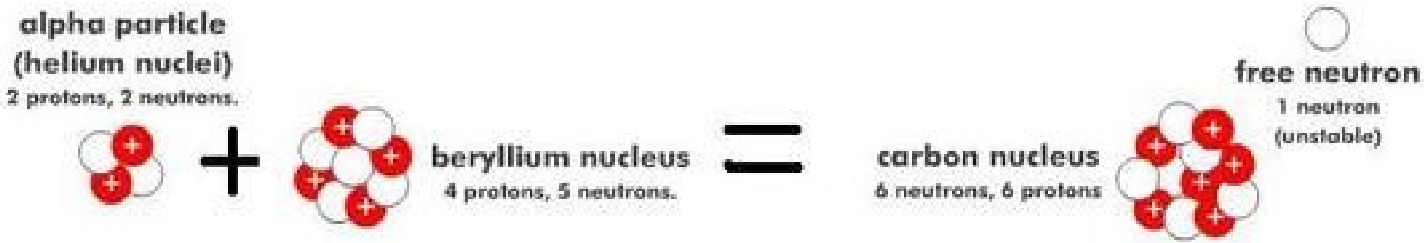
Spontaneous Fission (SF)



Induced Fission



(α,n) Reactions



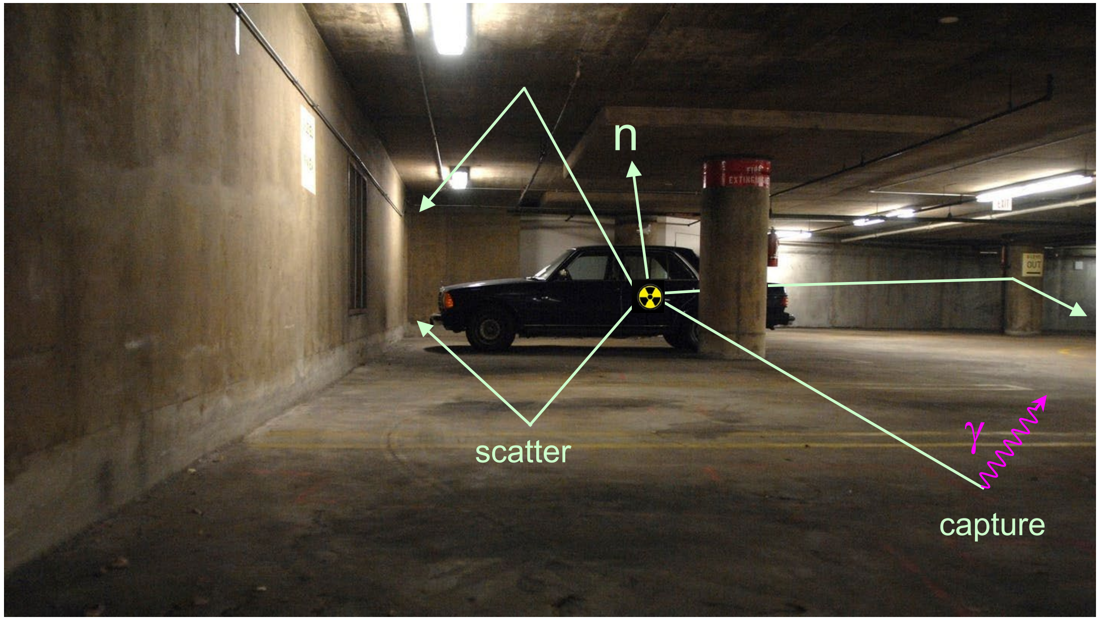
Neutron Sources

- Reactors and fuel
- Particle Accelerators
- (α,n) sources: used in research and industry
- Transuranics: spontaneous fission (Pu, Cf-252)
- Natural Neutron Background:
  - Generally from ‘cosmic ray’ spallation
  - Very weak signal compared with natural gamma-ray background

Almost all neutron sources are man-made!

Neutron Interactions

- Neutrons often can scatter and can be reflected
- Neutrons can also be captured by nuclei

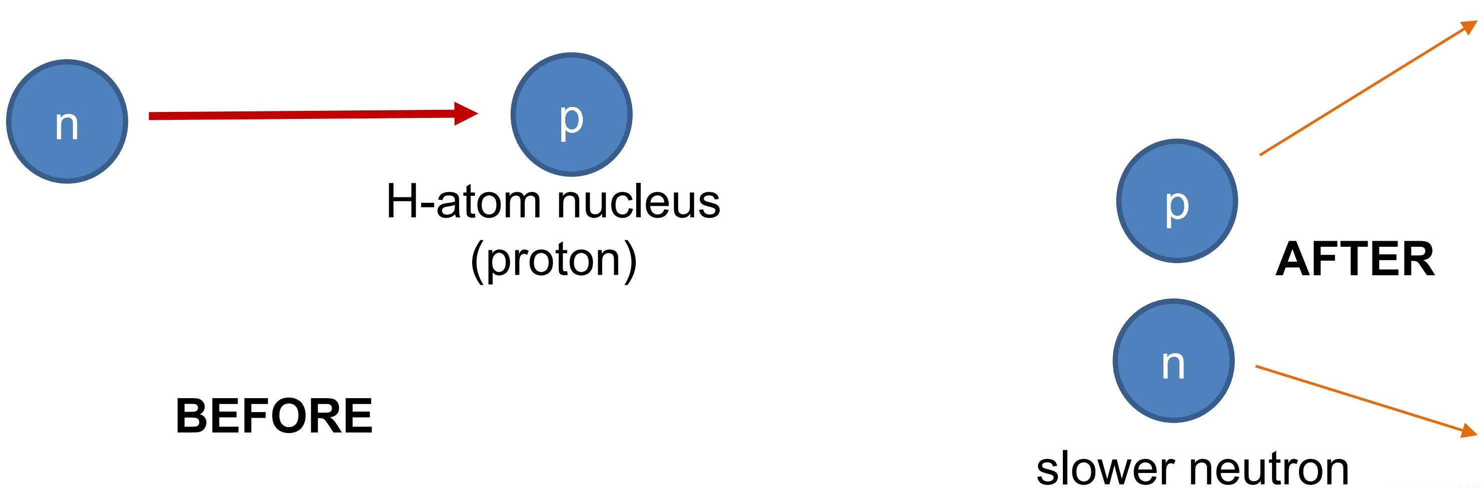


Neutron Moderation

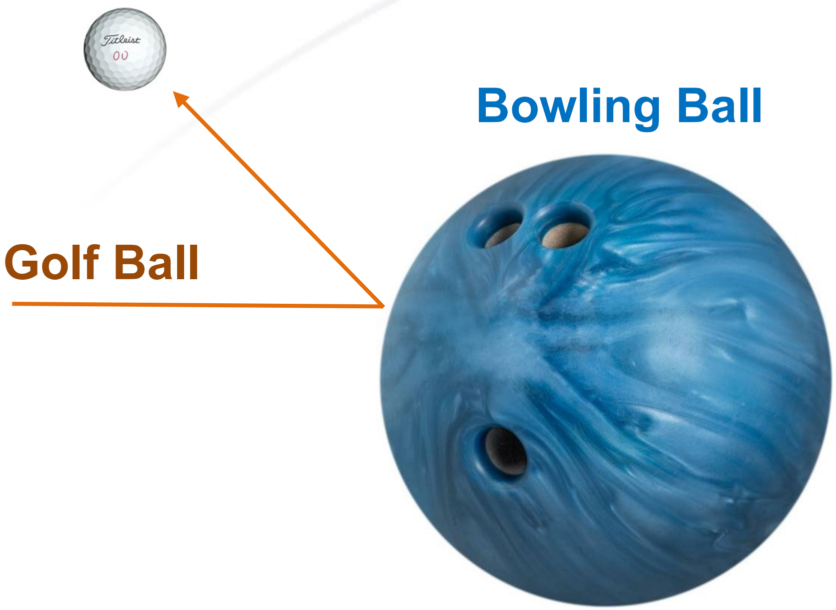
- Moderation is the slowing down (thermalization) of neutrons through collisions with *light* nuclei

Materials with lots of hydrogen (H_2O, HDPE, HE, etc.) make good moderators.

Fast neutron

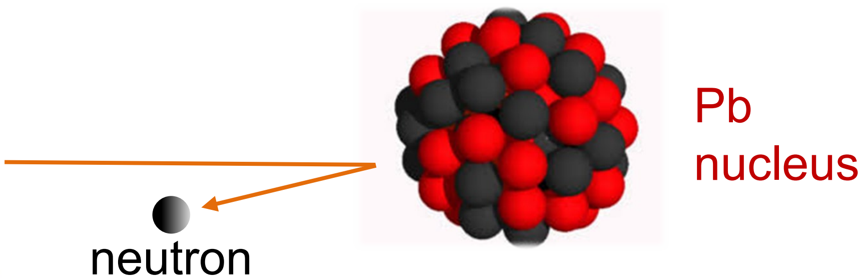


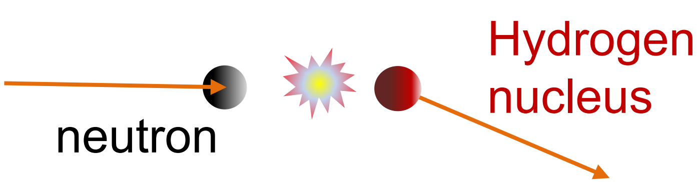
Neutron Moderation



Neutrons on Light Nuclei:
Good Moderation

Neutrons on Heavy Nuclei:
Poor Moderation

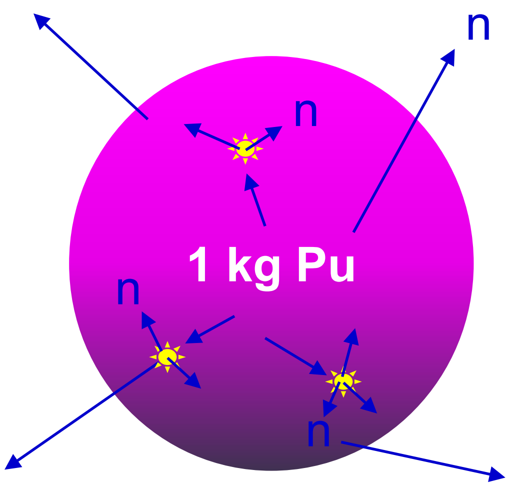




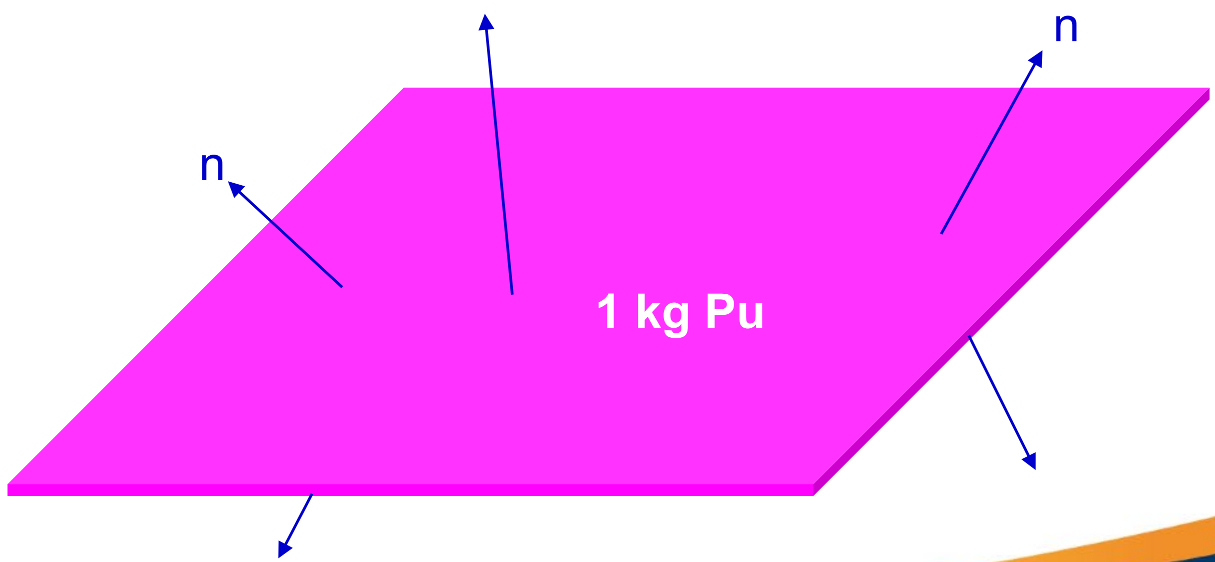
Neutron Multiplication

- How many neutrons are produced for every "starter" neutron (e.g. from SF)?

Neutrons in the sphere have a better chance of inducing fission (producing more neutrons!) before they escape

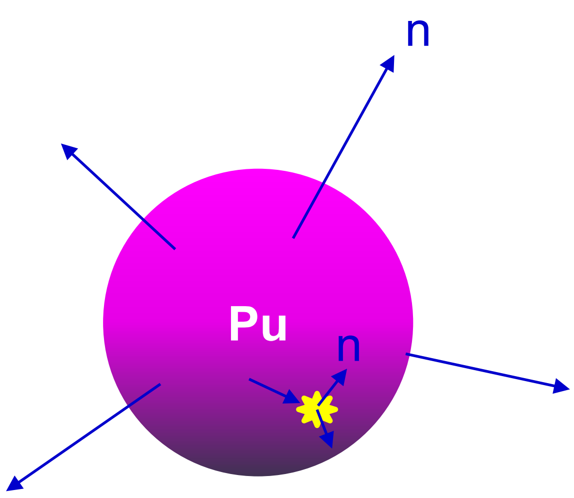


Neutrons in the flat plane more likely escape before inducing fission

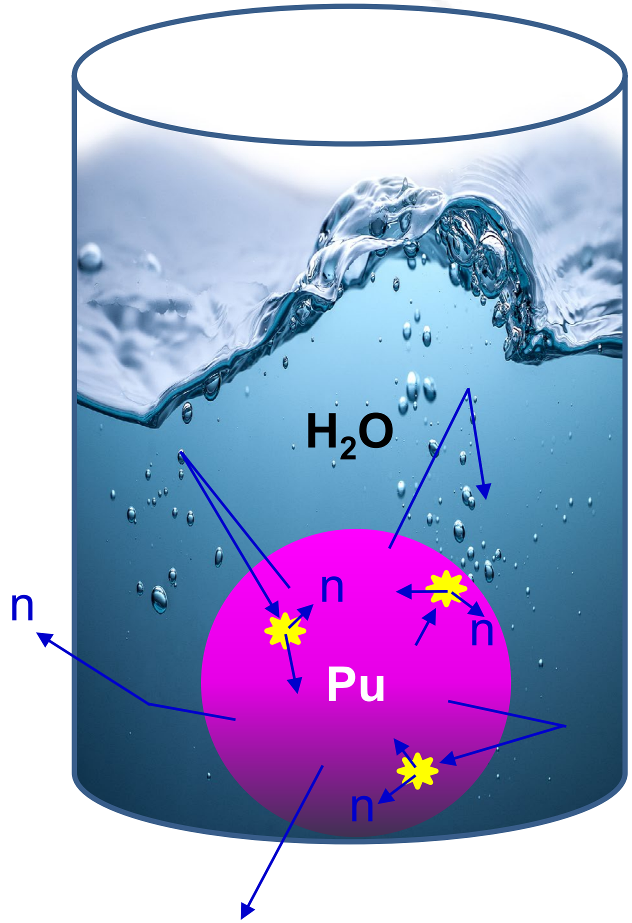


Reflection & Multiplication

Surrounding a neutron source with a reflecting material may send neutrons back into the material to induce more fissions.



Bare sphere

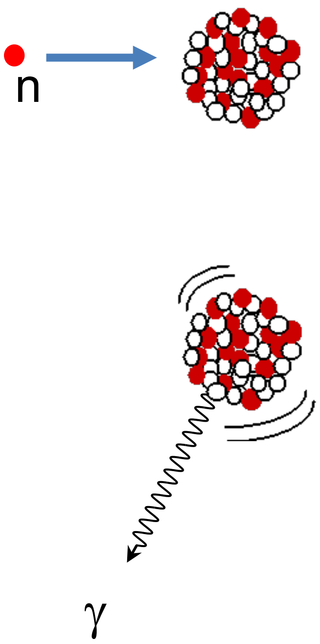


Gammas from Neutron Interactions

Neutron-Capture Gammas

Thermal neutron is absorbed by target nucleus.

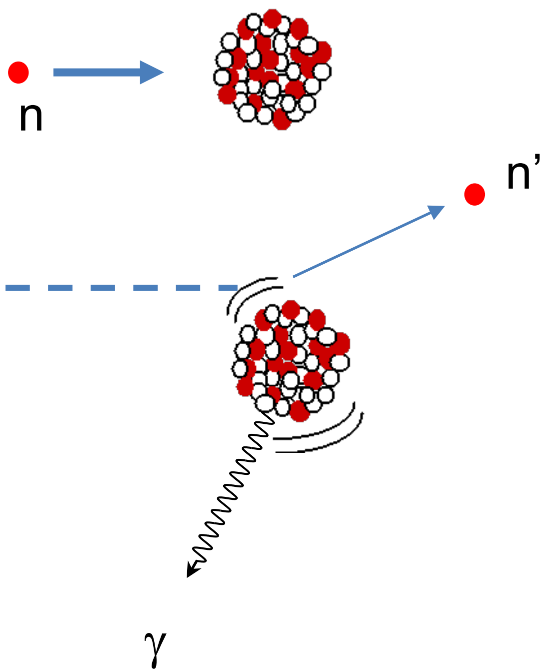
Resulting nucleus emits a gamma ray.



Neutron-Scatter Gammas

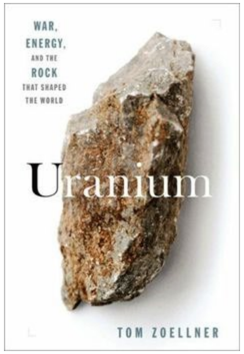
Fast neutron scatters from target nucleus.

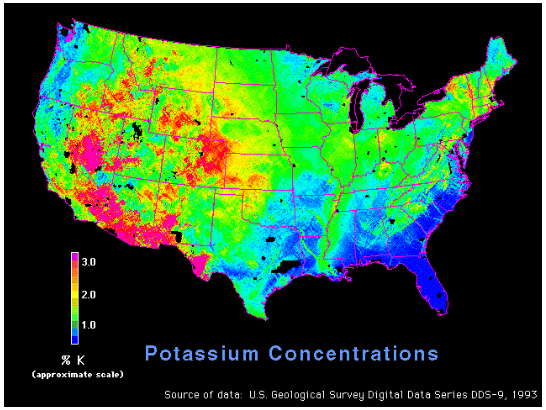
Resulting nucleus emits a gamma ray.



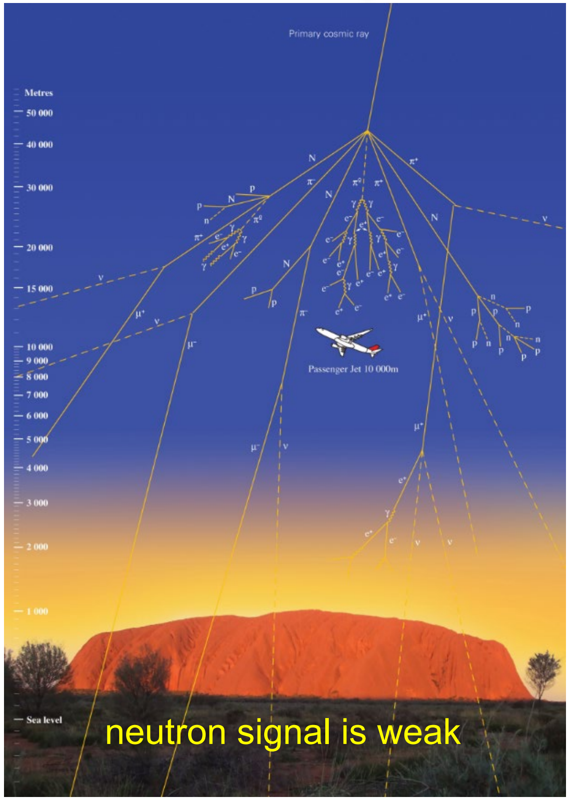
Natural Background Radiation

Gammas: From the Earth





Neutrons: From Space



U-238 Decay Series

Activity #1

List several things that can happen to neutrons in this picture

Activity #2

Which source is more penetrating “pound for pound”?
Which one is more *intense* *(assuming the labeled activity is current)* ?

122 keV
136 keV

1173 keV
1332 keV

Summary

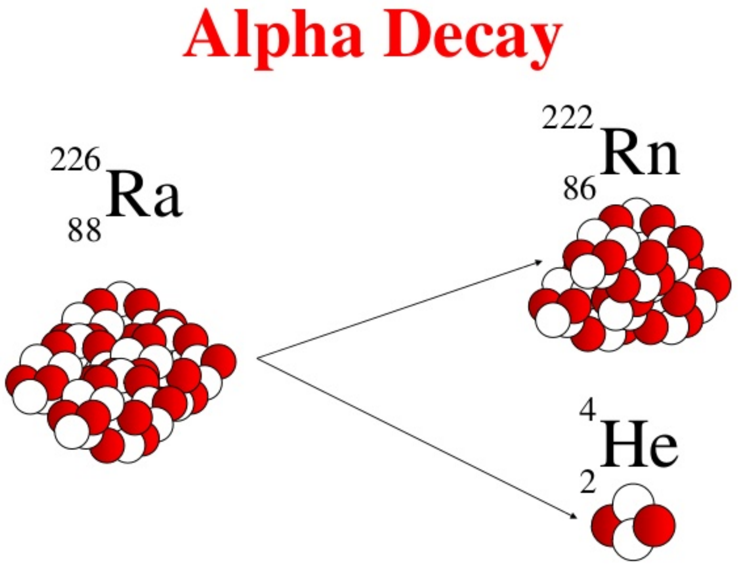
- Gamma rays are a form of light emanating from atomic nuclei.
- Gamma rays are penetrating, give us information particular to a radionuclide, and can be measured passively
- Shielding preferentially attenuates lower-energy gamma rays
- The 4 main components of the natural background are:
  - gamma rays from K-40
  - gamma rays from uranium decay series
  - gamma rays from thorium decay series
  - neutrons from cosmic ray spallation
- Examples of good neutron moderators are water, HDPE, and HE as these all contain lots of hydrogen

Appendix

- The following concepts have been covered in the previously-delivered HP presentation but are included here for reference.

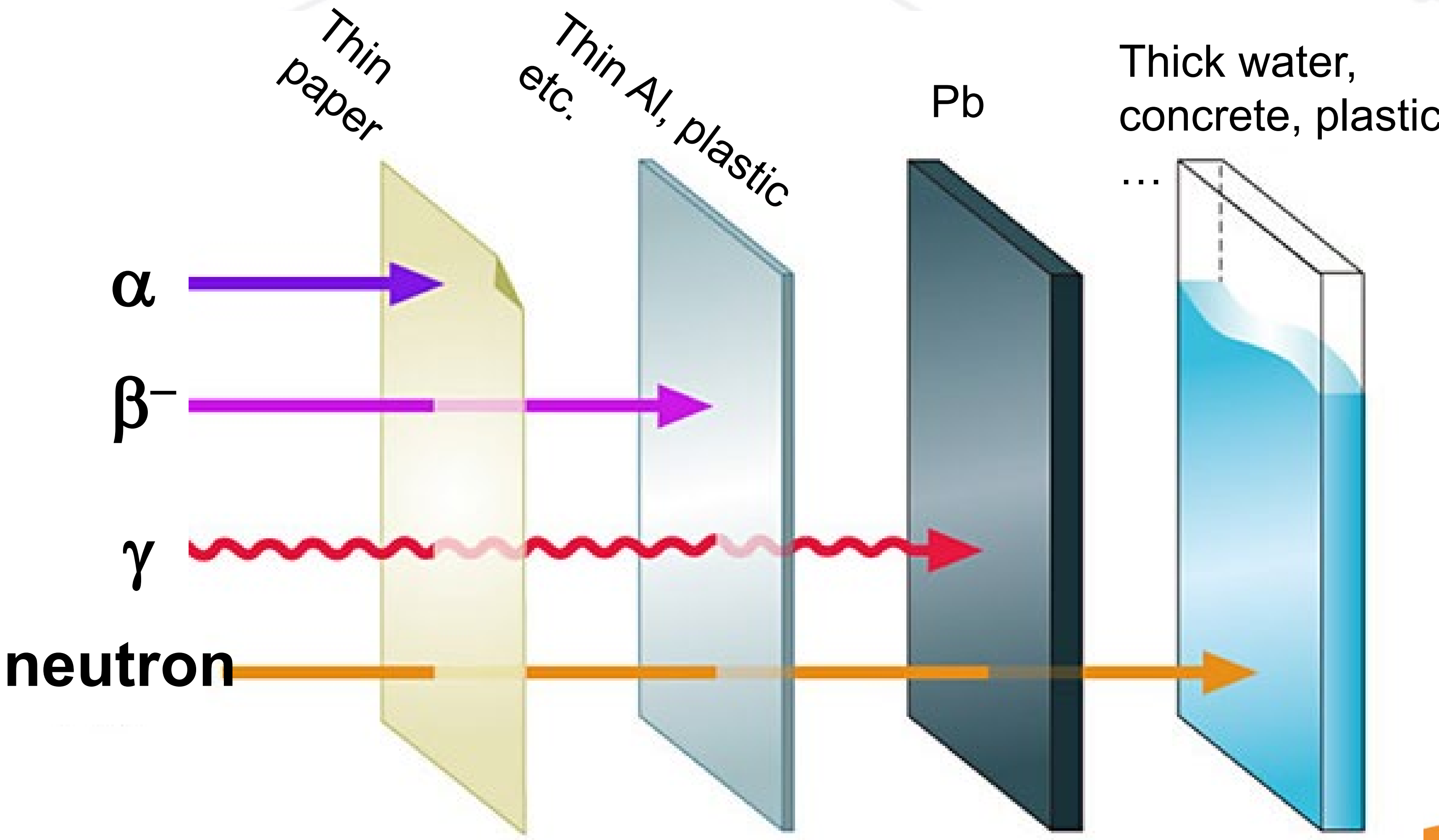
What is Radiation?

- When an atomic nucleus is unstable it emits something to get to its “ground state”.



This “something” is what we call “radiation”.

Radiation Types



Units of Radioactive Decay

- 1 disintegration per second = 1 Becquerel (Bq)
- 1 Curie (Ci) = 3.7E10 Bq
- 1 μCi = 1E-6 Ci (or 1 millionth of a Ci)
- Typical Check Sources:
  - ~ 1 to a few hundred μCi